



Testing of Advanced Conformal Ablative TPS

Matthew Gasch

NASA Ames Research Center, Moffett Field, CA, 94035

Parul Agrawal

ERC at NASA Ames Research Center, Moffett Field, CA, 94035

Robin Beck

NASA Ames Research Center, Moffett Field, CA, 94035

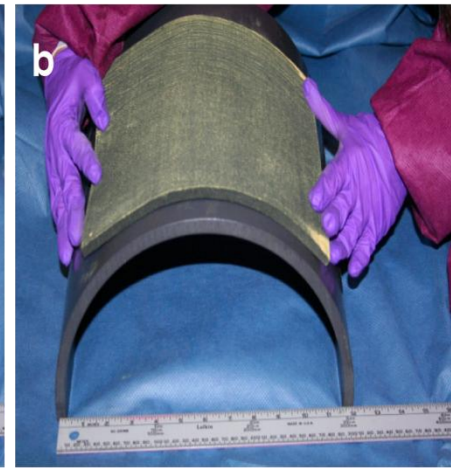
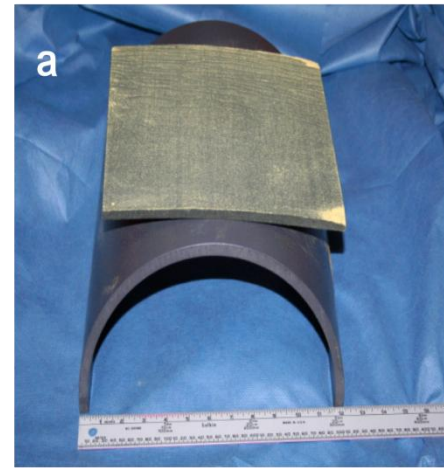
International Planetary Probe Workshop-10, June 17-21, 2013

Outline



- **Technology Description**
- **SPRITE Test Design and Results**
- **Summary**

- **Reinforcement on low density carbon or polymer felts**
 - High strain to failure eliminates need for strain isolation during attachment to rigid aeroshell (required for PICA)
 - Allows for large area ablators
 - Eliminates gaps and gap filler issues present with standard PICA
- **Impregnation with advanced polymer resins to improve properties**
 - Reduce thermal conductivity
 - Endothermic energy absorption due to decomposition of the resin
 - Increased char strength





- **Conformal TPS Materials Development to TRL 5**
- **Develop and demonstrate (via ground testing) a conformal ablator capable at 250 W/cm² and beyond**
 - Based on felt reinforcements that come in very large sizes
 - Reduced part counts (compared to PICA)
 - High strain-to-failure eliminates/reduces gap and gap filler issues common with PICA
- **Our assumptions are:**
 - Commercially available felt systems such as carbon felt, and simpler steps in making conformal TPS will lower the cost
 - Conformal is going to be less complex to integrate across a variety of carrier structure – lower design complexity
 - Conformal is going to be cheaper to manufacture and install

Test Campaigns



- **Test 1: 2012 Arcjet test series**
 - Assess the thermal performance of proposed materials over a broad range of conditions
 - Develop TPS-C instrumentation for developing and validating thermal response models from TPS materials testing in the arcjet
 - Down-select one conformal material for further testing.
- **Test 2: 2013 Arcjet test series**
 - Develop mid-fidelity material response models that can predict recession and in-depth temp response in support of mission design and analysis
 - Address attachment of conformal TPS to a rigid carrier structure and seam design between gore panels

SPRITE¹ – Small Probe Reentry Investigation for TPS Engineering

Advantages

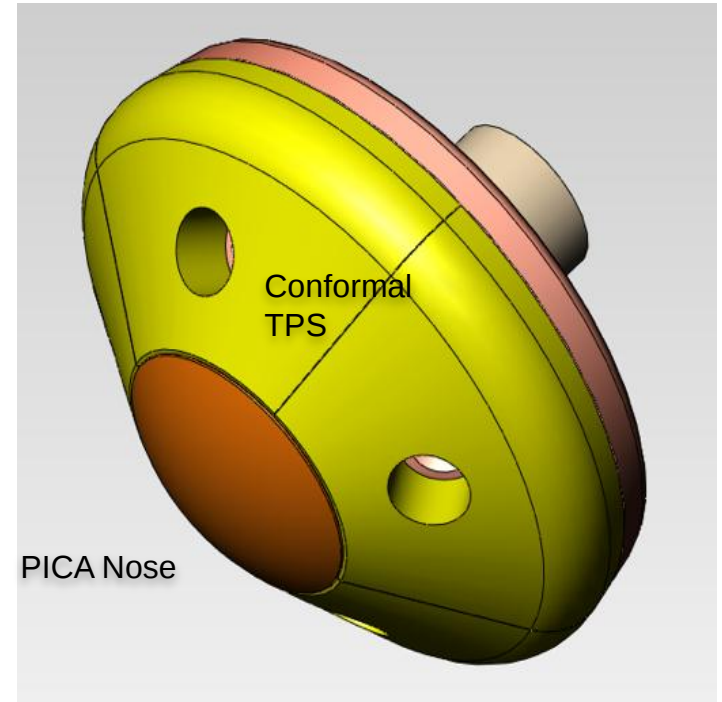
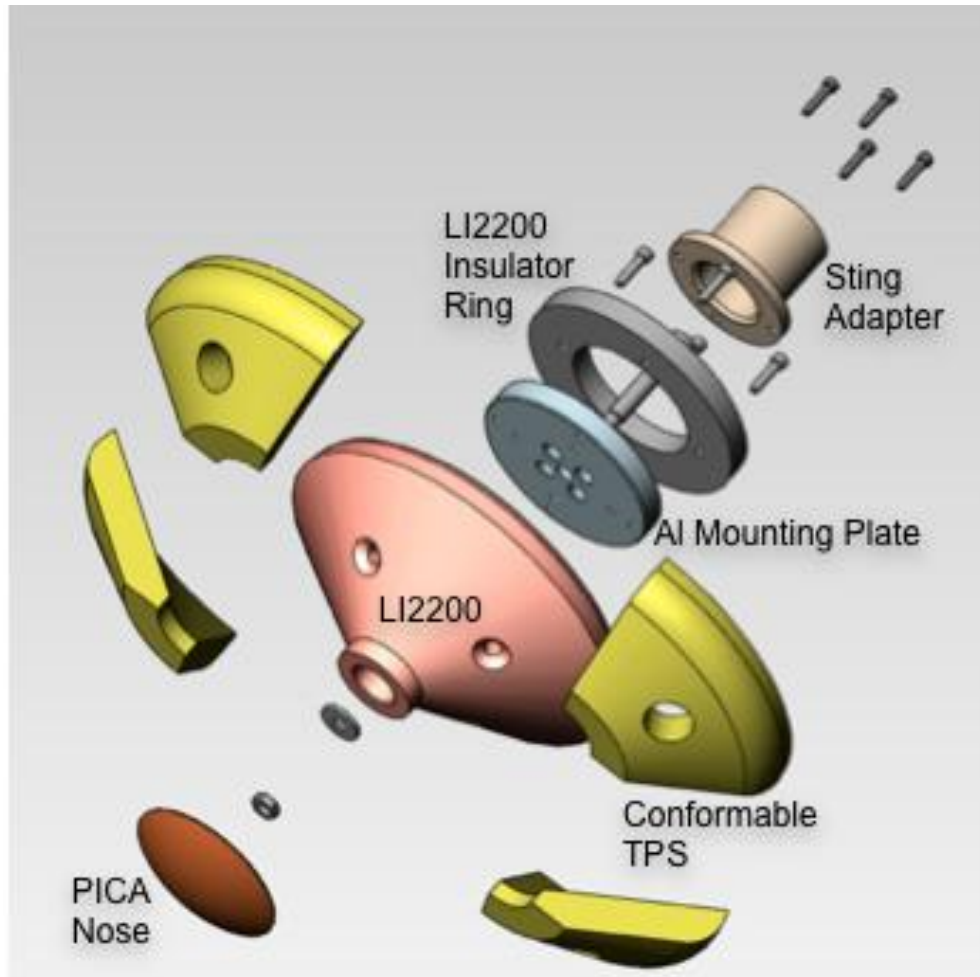
- Enables the testing in relevant environment
 - It is possible to obtain a flight like pressure, shear and heatflux distribution
- Can test standard TPS against conformal material within the same model resulting in cost savings.
- Enables testing of seams in relevant test conditions

¹Empey, D. M., Skokova, K.A., Agrawal P., Swanson G., Prabhu, D.K., Peterson K. H., and Venkatapathy E., “Small Probe Reentry Investigation for TPS Engineering (SPRITE)”, proceedings , 8th International Planetary Probe Workshop, Portsmouth, VA, 6-10 June 2011.

SPRITE Test Article Detail



CA250

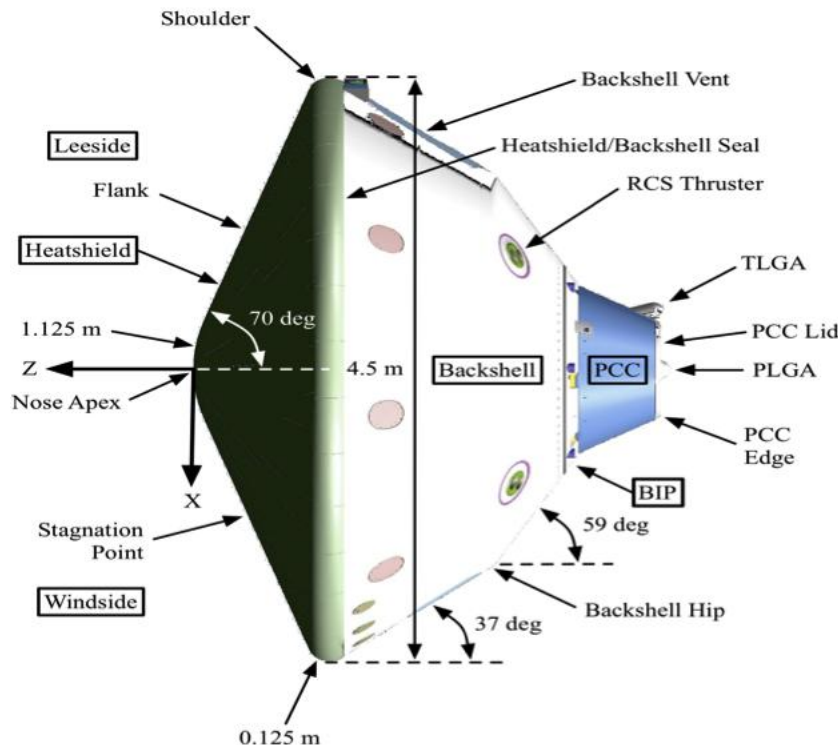


- 8-inch diameter
- 55° sphere cone

MSL Peak Aerothermal Environment

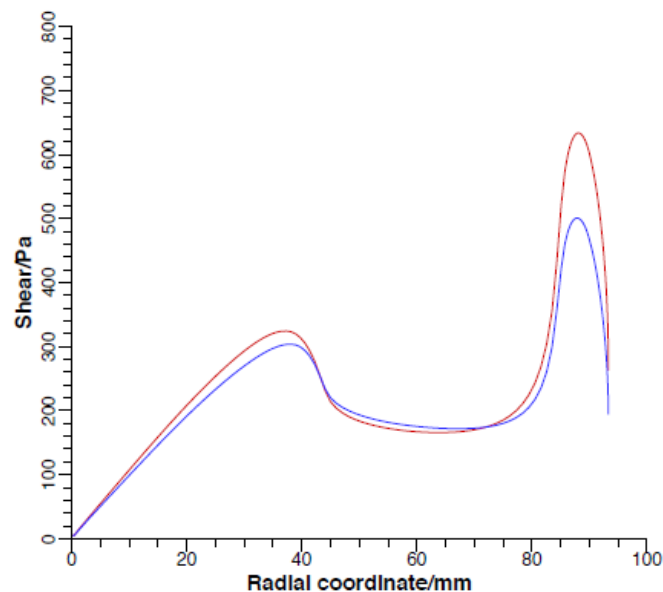
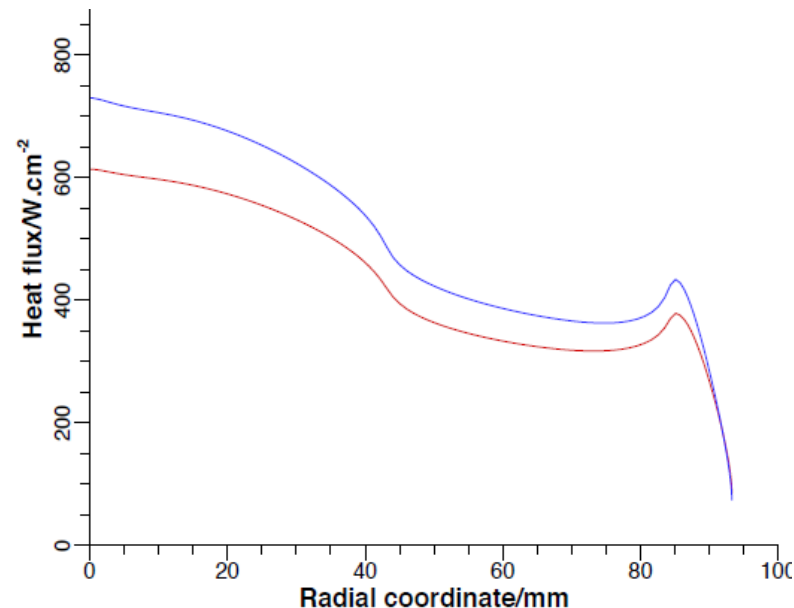
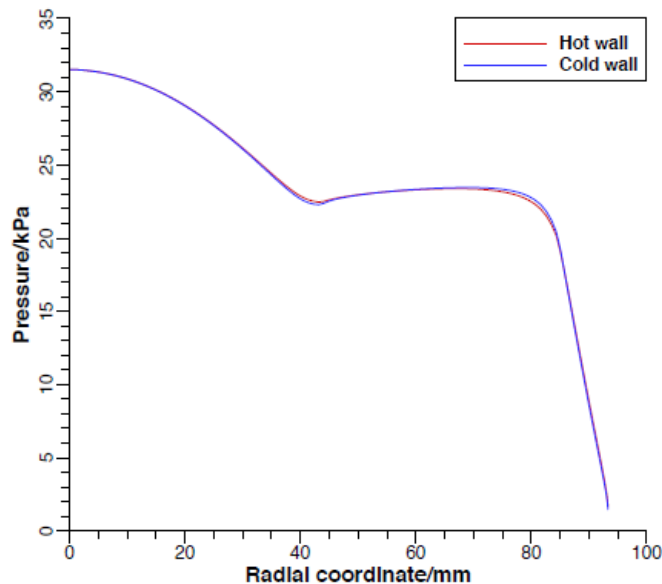


MSL Aerothermal Entry Environments	+3-sigma Value	09-TPS-02	Edquist, JPL D-34661, Rev B	
Location	Peak Heat Rate (W/cm ²)	Peak Shear (Pa)	Peak Pressure (atm)	Peak Heat Load (J/cm ²)
HS Leaside Flank	220.1	393.4	0.246	6103.5
HS Leaside Shoulder	225.7	465.4	0.242	6402.4
HS Leaside Shoulder	203.2	490.2	0.208	5895.3
Stagnation Point	59	5.4	0.332	2604.5
HS Nose Apex	119.2	127.4	0.239	4113.2
HS Windside Shoulder	114.4	216.7	0.242	4136.8
HS Windside Shoulder	103.8	240.5	0.172	3749.7



250 W/cm²,
0.33 Atm,
490 Pa Shear

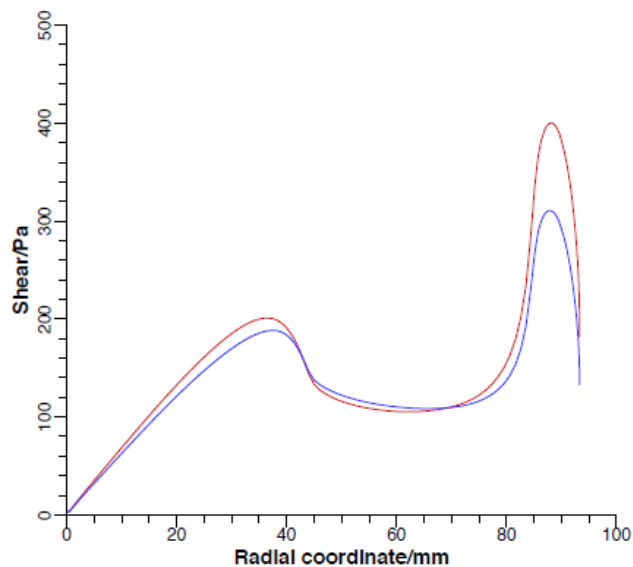
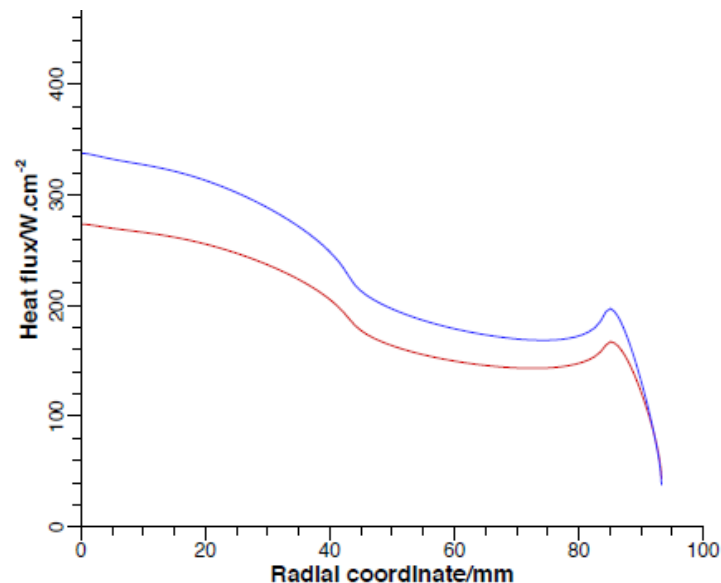
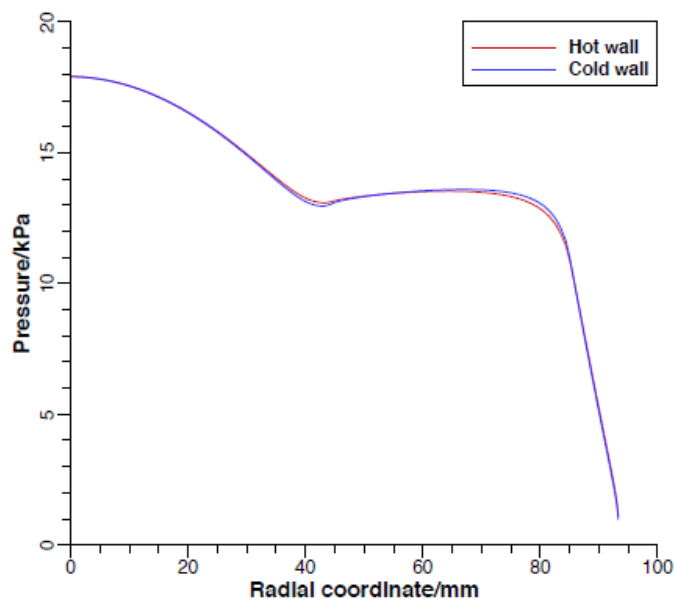
CFD Analysis: High Condition



High Condition “MSL”

~ 400 W/cm², ~ 24 kPa
Press. ~ 200 Pa shear on
Flank and ~ 500 Pa shear
On 0.8” R_b corner

CFD Analysis: Medium Condition



Medium Condition “MSL”

~ 180 W/cm², ~ 13 kPa
Press. ~ 150 Pa shear on
Flank and ~ 300 Pa shear
On 0.8” R_b corner

Test 1: Test Matrix and Instrumentation



Test Condition	Model	Heat-flux at the flank (W/cm ²)	Exposure Time (sec)
Medium	C-PICA	~180	60
Medium	C-SICA	~180	60
High	C-PICA	~400	30
High	C-SICA	~400	30

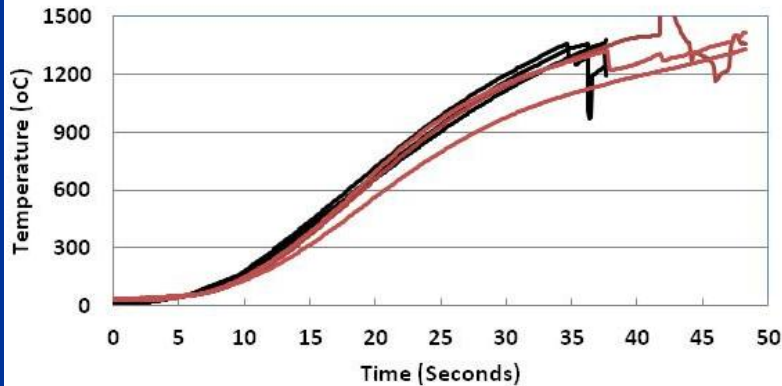
- **4 inch hemi calorimeters to characterize the flow**
- **Each model was instrumented with 4 TC- plugs with 3 TCs in each plug. The data from all the 12 TCs was collected during the test.**
- **Infrared camera and pyrometer were mounted to obtain surface temperature.**
- **Laser scans were obtained pre- and post- arcjet to measure recession.**

Test 1- TC data

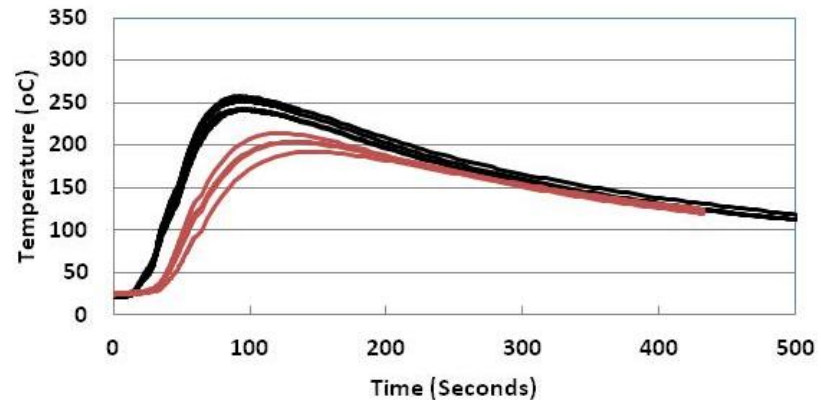
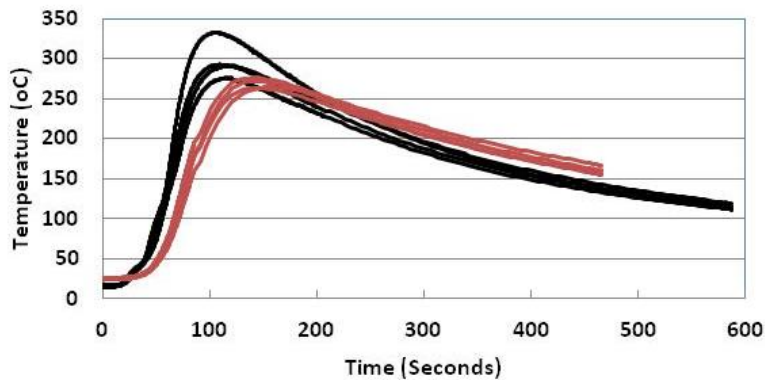
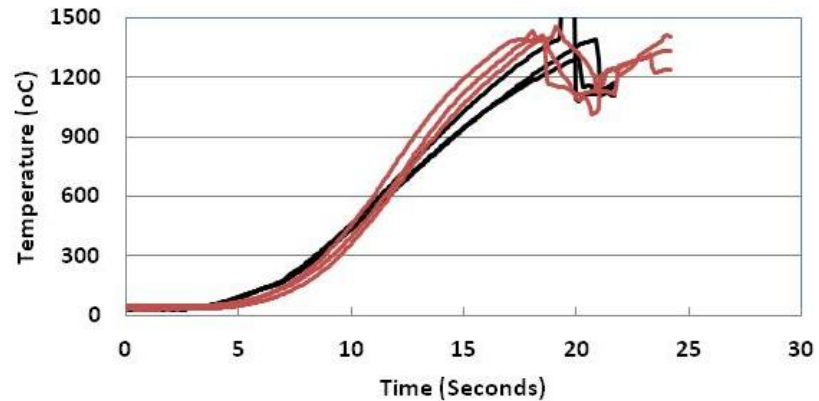


— C-PICA
— C-SICA

Medium Condition

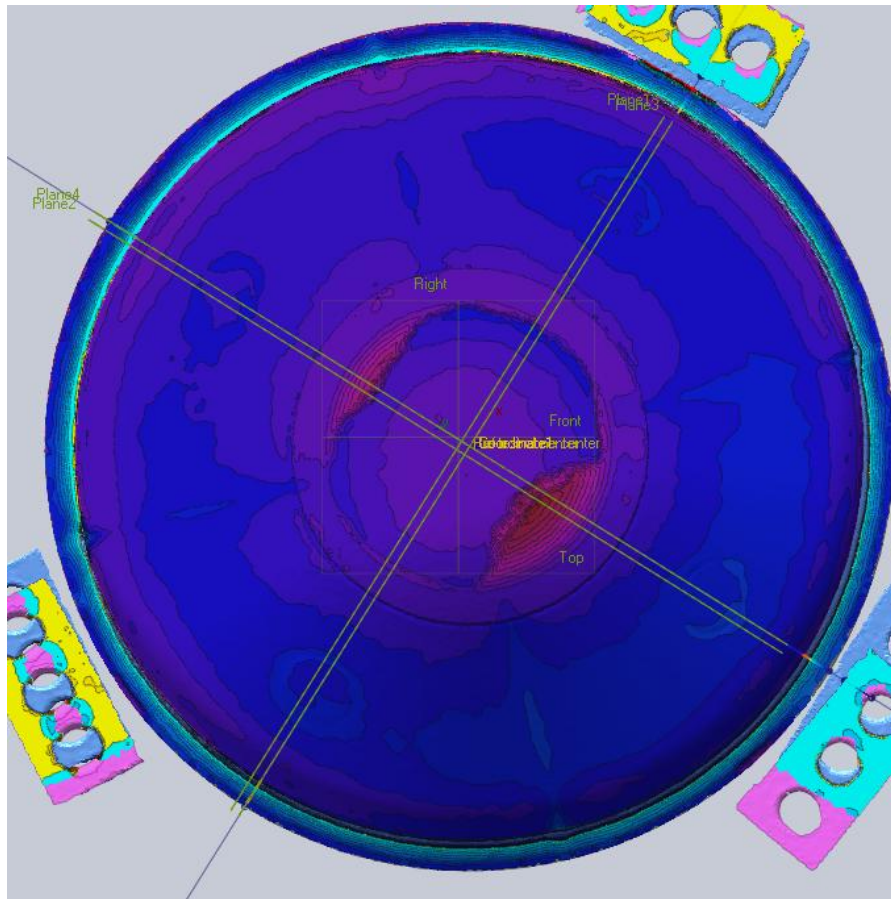


High Condition



- The conformal TC plugs worked well and we were able to obtain reasonable measurements from these test to develop thermal response model.

Test 1- recession



C-PICA model in high condition



Summary Table

Model	Test condition	Recession (mm)
C-PICA	High	3.5~4.2
C-PICA	Medium	5.8~6.3
C-SICA	High	3.1~4.0
C-SICA	Medium	2.5~4.0

Test 1 – Conclusions



Post test C-PICA



Post test C-SICA

- The tests proved that conformal ablator technology is a viable option.
- C-PICA was down-selected to be advanced to a higher TRL based on ease of processing , machining.
- The next step was to test gaps and seams for conformal ablator.

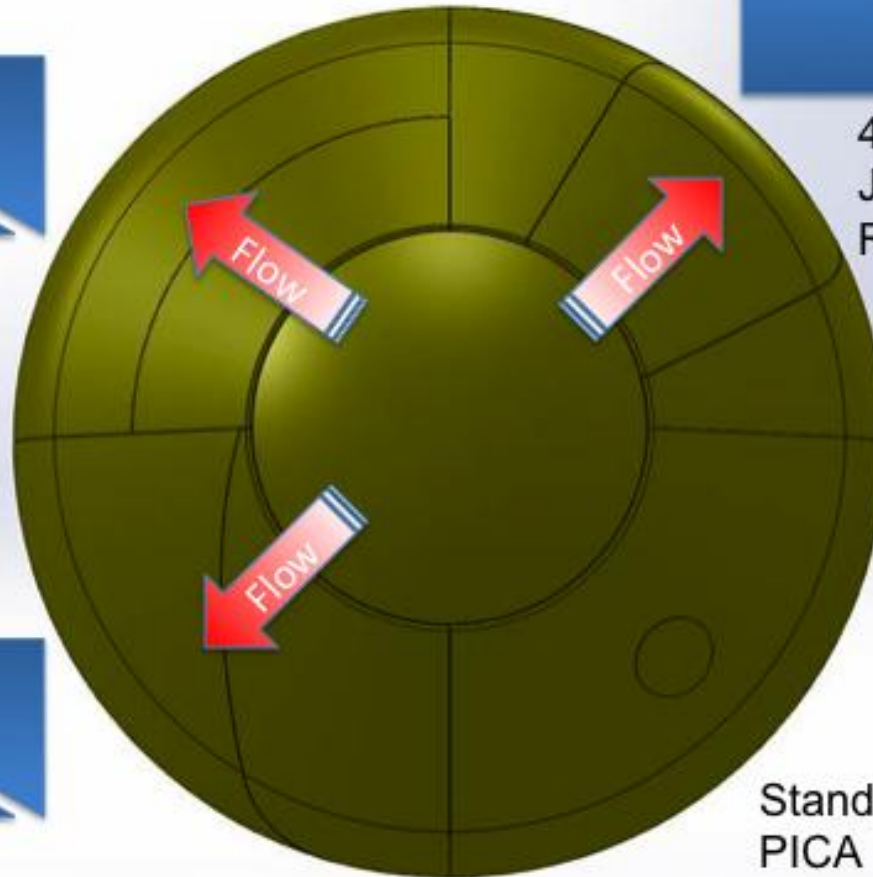
Test 2: Seam Model



45° Joint
Annular Cut



45° Joint
45° Radial
Cut



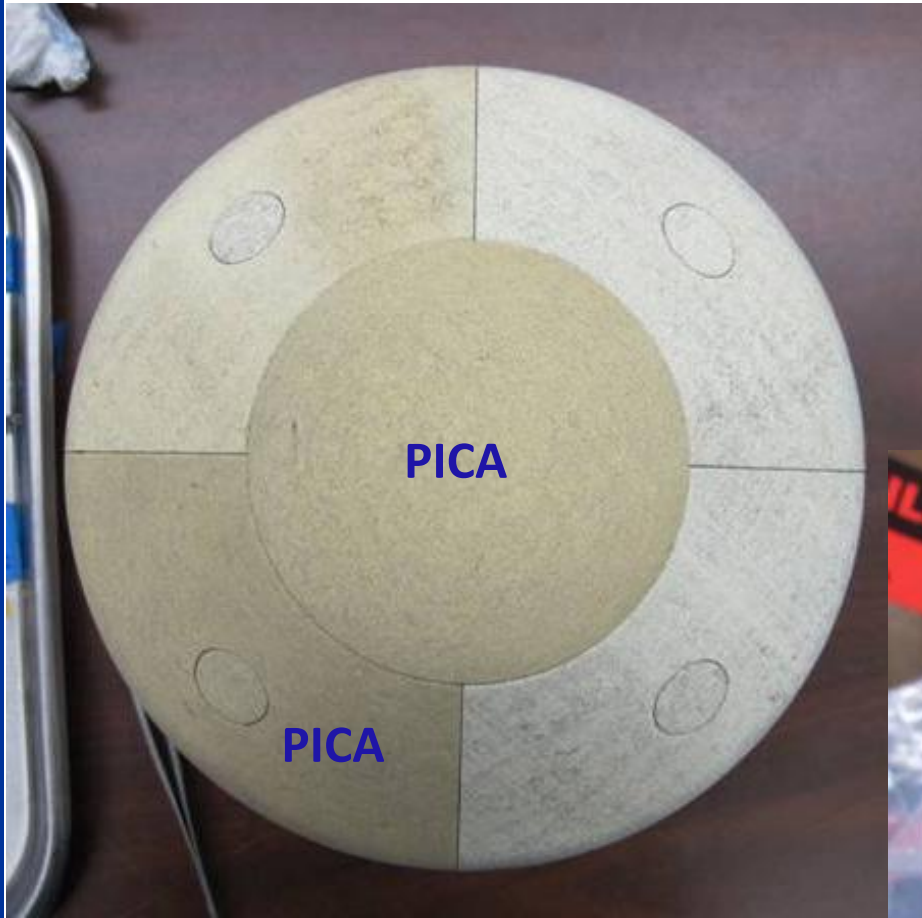
45° Lap
Joint
Radial Cut



45° Joint
Radial Cut

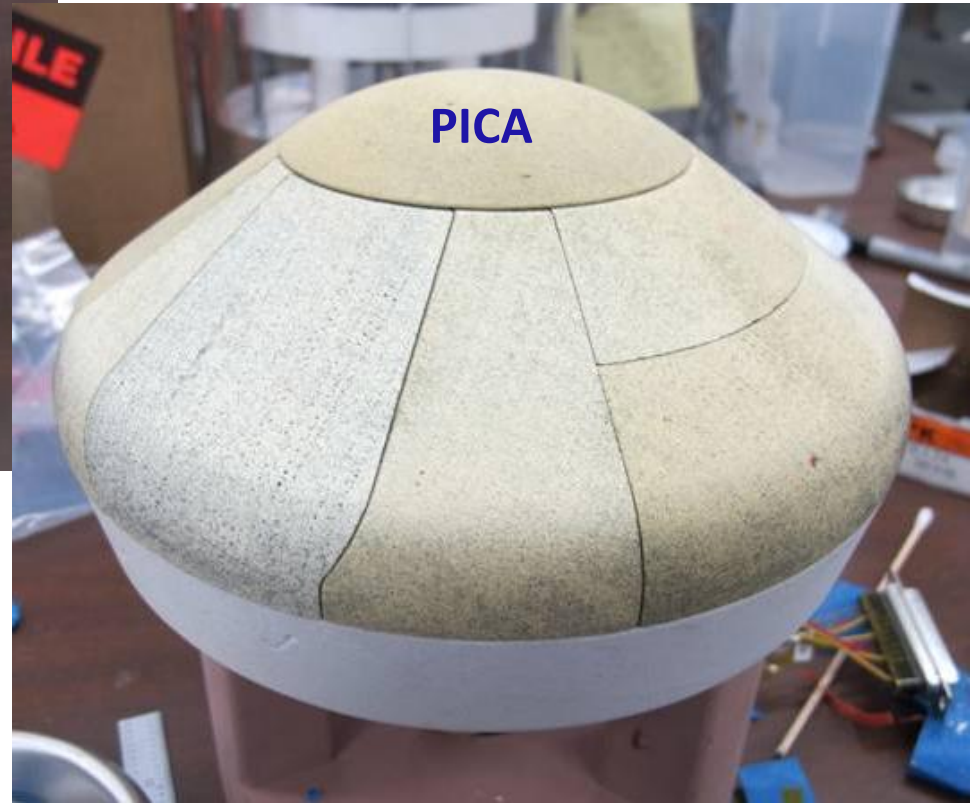
Standard
PICA

Test 2: Pre-Test Images



**Thermal Response
Model**

Seam Model



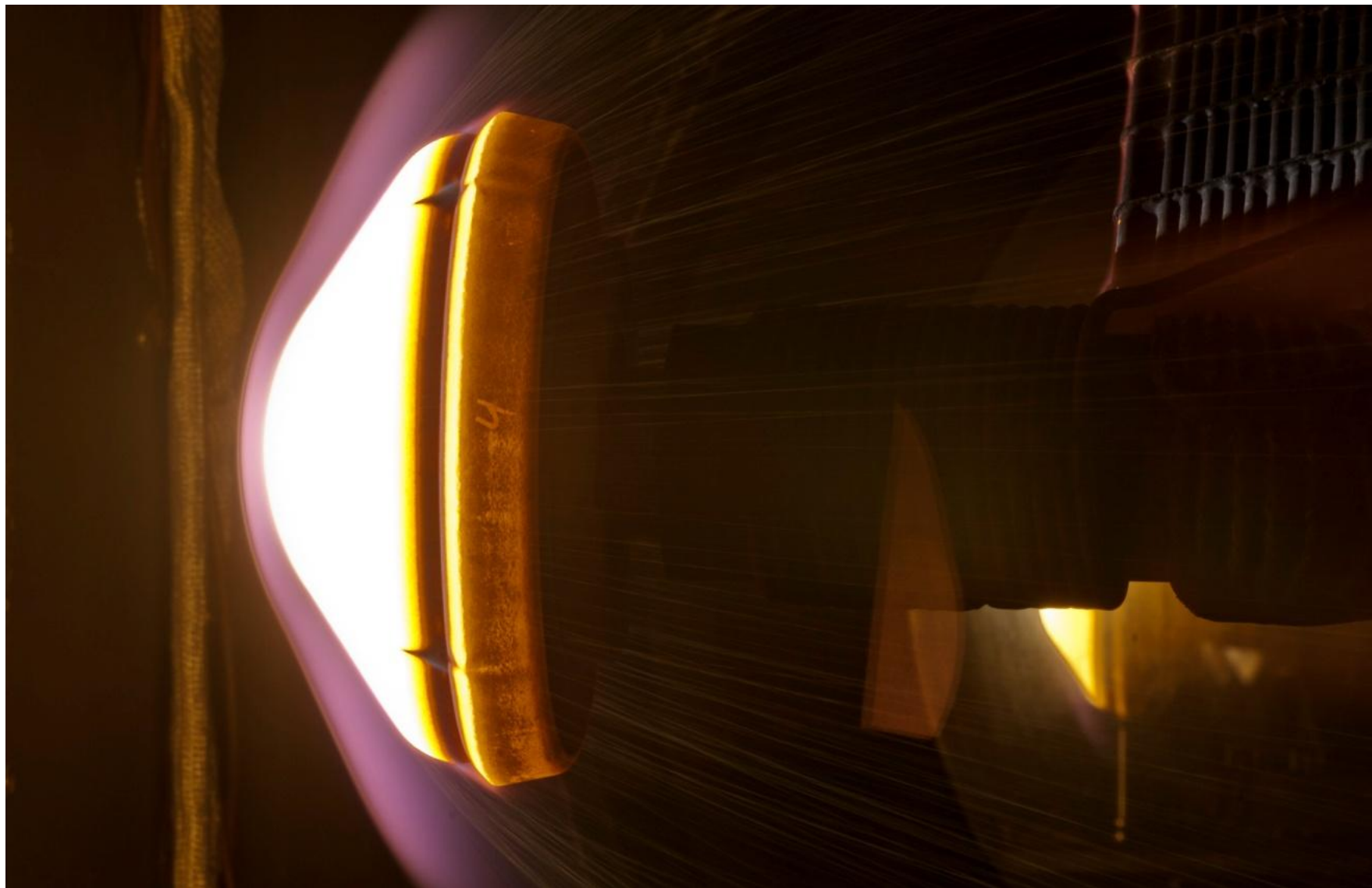
Test 2: Test Matrix and Instrumentation



Test Condition	Pressure (atm)	Heat-flux at the flank (W/cm ²)	Shear (Pa)	Exposure Time (sec)
1 (High)	0.25	~400	230	30
2 (Medium)	0.14	~180	143	60
3	0.07	~130	100	80
4	0.09	~40	80	100

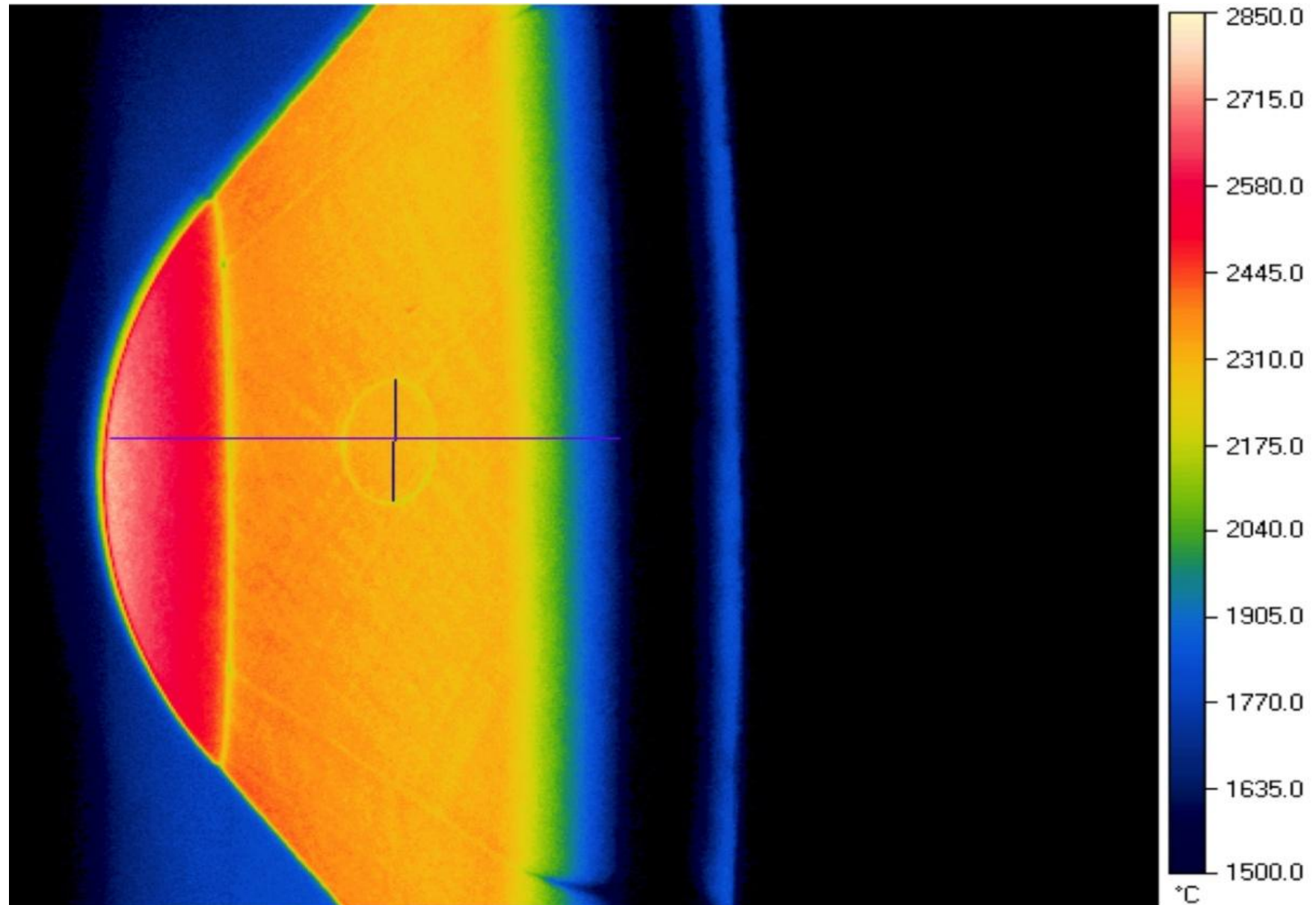
- Test Details:
 - Articles tested at 4 conditions: 40, 130, 180 & 400 W/cm²
 - 4-inch hemispherical calorimeters were used to characterize the flow
 - 4 TC plugs (0.15, 0.30 & 0.50-inch depth) – 1 in each TPS segment
 - IR and Pyrometer data were obtained for surface temperature
 - Pre and post- arcjet laser scans were obtained.

Model During Testing @ 400 W/cm²

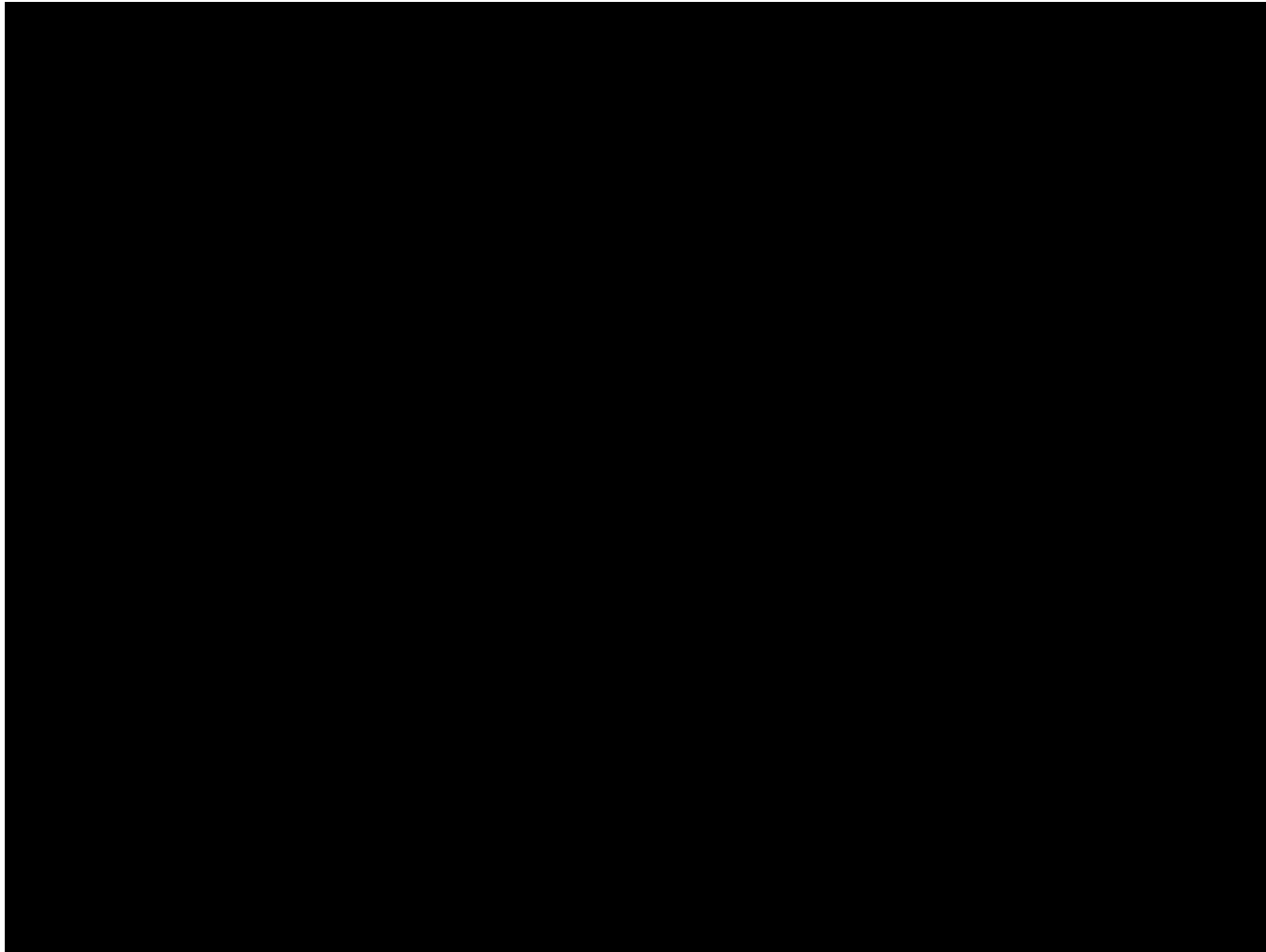


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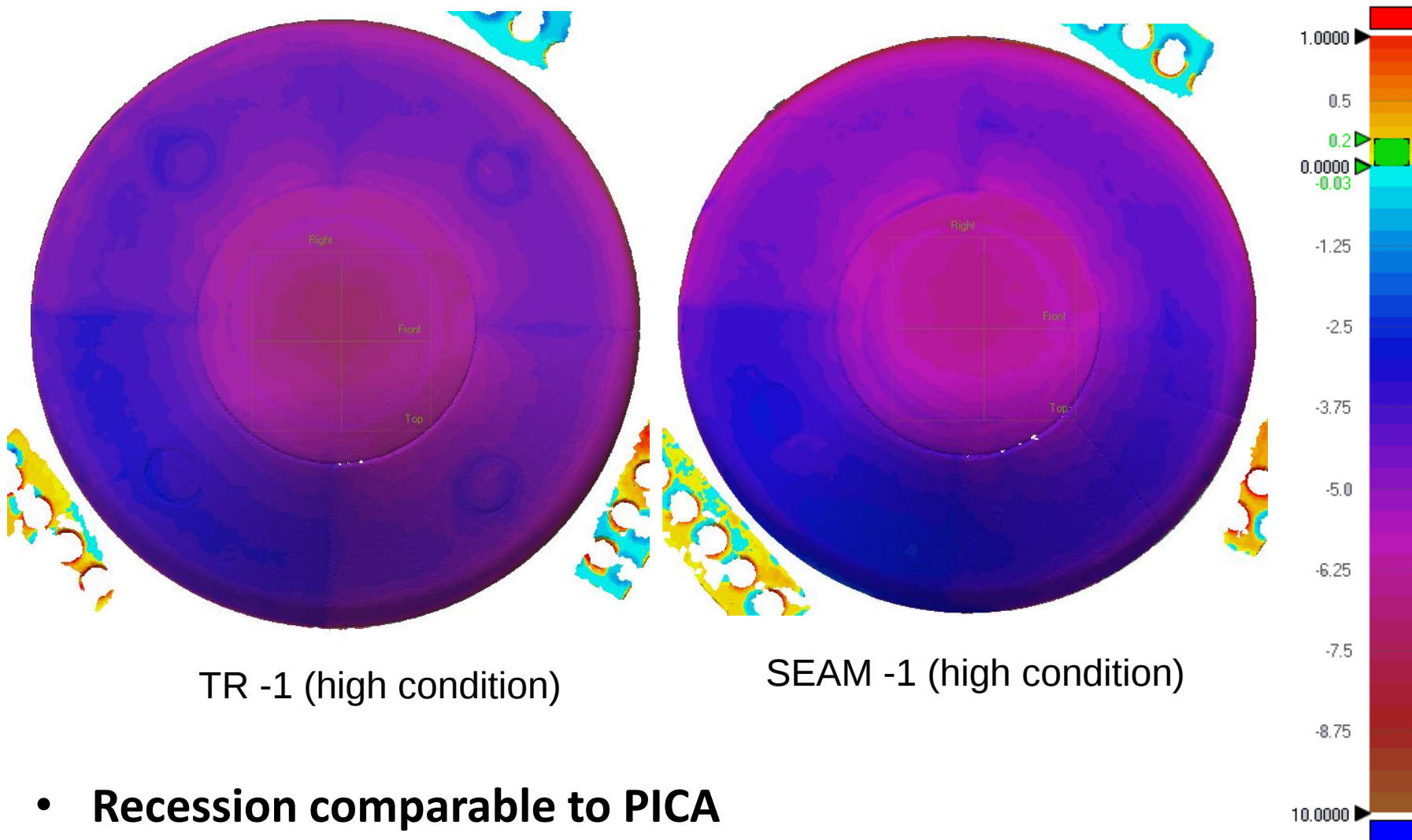
Model During Testing @ 400 W/cm²



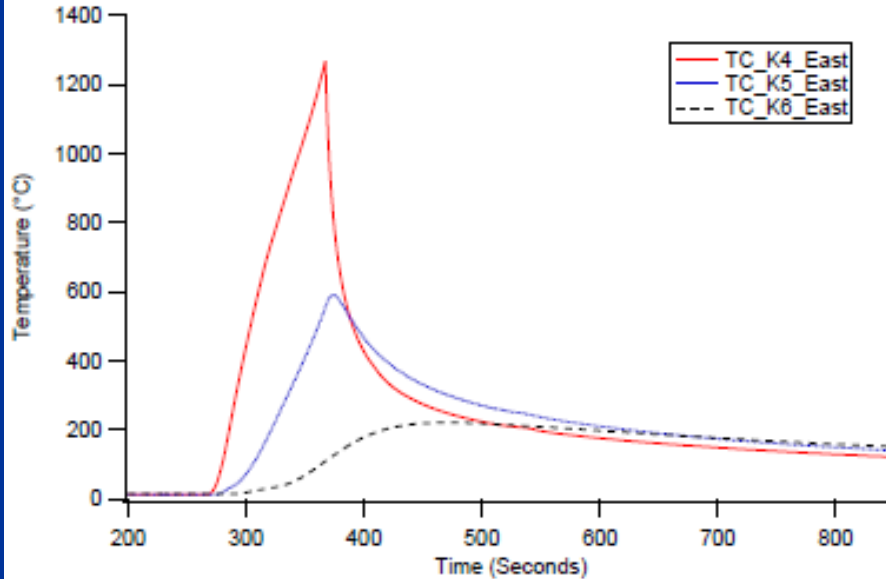
Test 2: Video of Seam Model



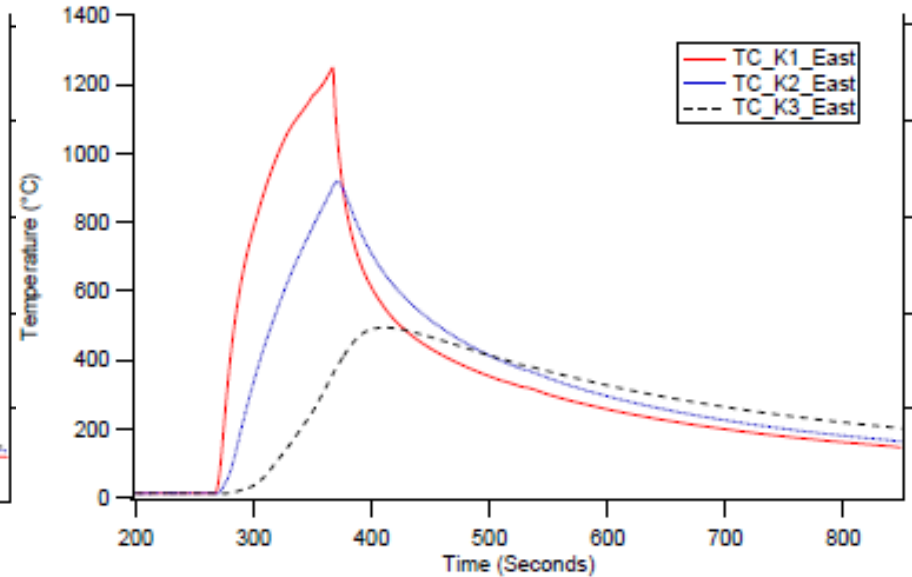
Test 2: Post test laser scan



Bondline Temperature: Run 4



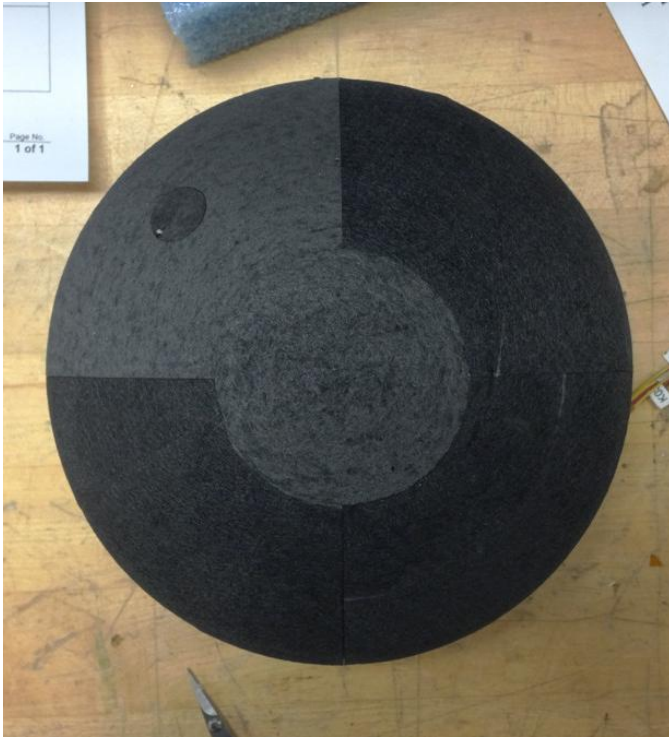
Conformal PICA



Standard PICA

- The thermocouple data consistently showed significantly lower bondline temperature for conformal PICA.

Post-Test – 400 W/cm², 30 sec



SPRITE Test Summary



- Objectives of the test were met:
 - Demonstrated applicability of conformable ablator on a curved structure at range of conditions from 40-400W/cm²
 - MSL-heat flux and COTS LEO shear conditions
 - Demonstrated advanced instrumentation of conformable ablators and gathered in-situ temperature data
 - Gathered recession and back-face temperature data on conformable ablators in a representative shear environment
 - Evaluated 5 seam designs. All the seams performed very well in the arcjet environments. No widening of gaps, redeposit etc were observed during the test.

The two tests proved that Conformal PICA is a viable technology solution that addresses the issues of gap fillers and seams with standard PICA , while proving a lower bondline temperature.